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Status and perspectives of $\sin 2\alpha$ measurements

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In the neutral B meson system, it is possible to measure the CKM angle α using the decay mode $b \to u\bar{u}d$ in the presence of pollution from gluonic $b \to d$ penguin decays. Here the recent status of the measurements of CP-violating asymmetry parameters using time-dependent analyses in $B^0 \to \pi^+\pi^-$ and $B^0 \to \rho\pi$ decays and the perspectives of a $\sin 2\alpha$ measurement are presented.

1 Introduction

In 1973, Kobayashi and Maskawa (KM) proposed a model where CP violation is accommodated as an irreducible complex phase in the weak-interaction quark mixing matrix [1]. Recent measurements of the CP-violating asymmetry parameters $\sin 2\beta$ $(= \sin 2\phi_1)$ [2] by the Belle [3] and BaBar [4] Collaborations established CP violation in the neutral B meson system. Measurements of other CP-violating asymmetry parameters provide important tests of the KM model. Any mode with a contribution from $b \to u\bar{u}d$ is a possible source of measurement of the Cabibbo-Kobayashi-Maskawa (CKM) angle α $(= \phi_2)$. Here the recent status of the measurements of CP-violating asymmetry parameters using time-dependent analyses in $B^0 \to \pi^+\pi^-$ and $B^0 \to \rho\pi$ decays [5] and the perspectives of a $\sin 2\alpha$ measurement are presented.

2 $B^0 \to \pi^+\pi^-$ decays

The $B^0 \to \pi^+\pi^-$ decay is one of the important modes for the measurement of $\sin 2\alpha$. The KM model predicts CP-violating asymmetries in the time-dependent rates for B^0 and $\bar{B}^0$ decays to a common CP eigenstate, f_{CP}. In the decay chain $\Upsilon(4S) \to B^0\bar{B}^0 \to f_{CP} f_{\rm tag}$, in which one of the B mesons decays at time t_{CP} to f_{CP} and the other decays at time $t_{\rm tag}$ to a final state $f_{\rm tag}$ that distinguishes between B^0 and $\bar{B}^0$, the $B^0 \to \pi^+\pi^-$ decay rate has a time-dependence given by

$$\mathcal{P}^q_{\pi\pi}(\Delta t) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}} [1 + q \cdot \{\mathcal{S}_{\pi\pi} \sin(\Delta m_d \Delta t) - C_{\pi\pi} \cos(\Delta m_d \Delta t)\}] , \quad (1)$$

where τ_{B^0} is the B^0 lifetime, Δm_d is the mass difference between the two B^0 mass eigenstates, $\Delta t = t_{CP} - t_{\rm tag}$, and the b-flavor charge $q = +(-1)$ when the tagging B meson is a $B^0(\bar{B}^0)$. The CP-violating asymmetry parameters $\mathcal{S}_{\pi\pi}$ and $C_{\pi\pi}$ $(= -\mathcal{A}_{\pi\pi})$ [6] defined in Eq. (1) are expressed as

$$C_{\pi\pi} = \frac{1 - |\lambda_{\pi\pi}|^2}{1 + |\lambda_{\pi\pi}|^2}, \qquad \mathcal{S}_{\pi\pi} = \frac{2\mathrm{Im}\lambda_{\pi\pi}}{1 + |\lambda_{\pi\pi}|^2}, \quad (2)$$

where $\lambda_{\pi\pi}$ is a complex parameter that depends on both B^0-$\bar{B}^0$ mixing and on the amplitudes for B^0 and $\bar{B}^0$ decay to $\pi^+\pi^-$. A measurement of time-dependent CP-violating asymmetries in the mode $B^0 \to \pi^+\pi^-$ is sensitive to direct CP violation and the CKM angle α. If the decay proceeded only via a $b \to u$ tree amplitude, $\mathcal{S}_{\pi\pi} = \sin 2\alpha$ and $C_{\pi\pi} = 0$, or equivalently $|\lambda_{\pi\pi}| = 1$. The situation is complicated by the possibility of significant contributions from gluonic $b \to d$ penguin amplitudes that have a different weak phase and additional strong phases. In general, $\mathcal{S}_{\pi\pi}$ is given by $\sqrt{1 - C^2_{\pi\pi}} \sin 2\alpha_{eff}$ Here $\alpha_{eff} - \alpha$ $(=\theta)$ depends on the magnitudes and relative weak and strong phases of the tree and penguin amplitudes. As a result, $\mathcal{S}_{\pi\pi}$ may not be equal to $\sin 2\alpha$ and direct CP violation, $C_{\pi\pi} \neq 0$, may occur.

Candidate B mesons are reconstructed kinematically using two variables, the energy difference $\Delta E \equiv E^{cms}_B - E^{cms}_{beam}$ and the beam-energy constrained mass $M_{\rm bc} \equiv \sqrt{(E^{cms}_{beam})^2 - (p^{cms}_B)^2}$ [7], where E^{cms}_{beam} is the cms beam energy, and E^{cms}_B and p^{cms}_B are the cms energy and momentum of the B candidate.

Charged tracks in $B^0 \to h^+h'^-$ candidates are identified as charged pions or kaons. Here h and h' represent a π or K. The Belle Collaboration uses the likelihood ratio (KID) for a particle to be a $K^\pm$ meson, which is based on the combined information from the Aerogel Cherenkov counter and CDC dE/dx measurement. Tracks are positively identified as pions with KID<0.4 for $B^0 \to \pi^+\pi^-$ candidates. The BaBar Collaboration uses the Cherenkov angle measurement θ_c from a detector of internally reflected Cherenkov light. The probability density function (PDF) from the difference between measured and expected values of θ_c is used in the extended likelihood function for the fit to extract yields and CP parameters.

Background from the process $e^+e^- \to q\bar{q}$ continuum $(q = u, d, s, c)$ are suppressed by their event topology. The Belle Collaboration forms signal and background likelihood functions $\mathcal{L}_S$ and $\mathcal{L}_{BG}$ from a Fisher discriminant determined from six modified Fox-Wolfram moments [8] and the cms B flight direction with respect to the beam axis. The continuum background is reduced by impos-

ing requirements on the likelihood ratio $LR = \mathcal{L}_S/(\mathcal{L}_S + \mathcal{L}_{BG})$ for different flavor-tagging dilution factor intervals. The BaBar Collaboration uses the angle θ_S between the sphericity axis of the B candidate and the sphericity axis of the remaining particles in the cms frame, and cut on $|\cos\theta_S|$. The shapes of Fisher discriminant $\mathcal{F}$ [9] for signal and background events are included as PDFs in the maximum likelihood fit.

Leptons, kaons, and charged pions that are not associated with the reconstructed B candidate are used to identify the flavor of the accompanying B meson.

The vertex reconstruction algorithm is the same as that used for the $\sin 2\beta$ ($\sin 2\phi_1$) analysis. The time difference Δt is obtained from the measured distance between the z positions along the beam direction of the $B^0_{\pi\pi}$ and $B^0_{\rm tag}$ decay vertices and the boost factor $\beta\gamma$ of the e^+e^- system.

Fig. 1 and Fig. 2 show distributions of ΔE for events enhanced in signal $\pi^+\pi^-$ and $K^\mp\pi^\pm$ decays from the Belle Collaboration [10] and the BaBar Collaboration [11], respectively. The Belle and BaBar Collaborations obtained the following results using an unbinned maximum likelihood fit based on 85×10^6 and $88\times10^6 B\overline{B}$ pairs, respectively,:

$$C_{\pi\pi} = -0.77 \pm 0.27 \pm 0.08, \quad \mathcal{S}_{\pi\pi} = -1.23 \pm 0.41^{+0.08}_{-0.07} \quad \text{(Belle)},$$

$$C_{\pi\pi} = -0.30 \pm 0.25 \pm 0.04, \quad \mathcal{S}_{\pi\pi} = -0.02 \pm 0.34 \pm 0.05 \quad \text{(BaBar)}.$$

The first and the second errors correspond to statistical and systematic errors, respectively, unless otherwise stated. The average values of $C_{\pi\pi}$ and $\mathcal{S}_{\pi\pi}$ are

$$C_{\pi\pi} = -0.49 \pm 0.19, \qquad \mathcal{S}_{\pi\pi} = -0.47 \pm 0.26,$$

and the difference of the results between the Belle and BaBar Collaborations is 2.2σ [12]. In Fig. 3 and Fig. 4 the Δt distributions for events enhanced in signal $B^0 \to \pi^+\pi^-$ decays are shown for the Belle Collaboration [10] and the BaBar Collaborations [11], respectively.

Fig. 5 shows the two-dimensional confidence regions in the $\mathcal{A}_{\pi\pi}(= -C_{\pi\pi})$ vs. $\mathcal{S}_{\pi\pi}$ plane using the Feldman-Cousins frequentist approach [13]. In order to form confidence intervals, the $\mathcal{A}_{\pi\pi}$ and $\mathcal{S}_{\pi\pi}$ distributions of the results of fits to MC pseudo-experiments for various input values of $\mathcal{A}_{\pi\pi}$ and $\mathcal{S}_{\pi\pi}$ are used for the Belle result, and the obtained errors of $\mathcal{A}_{\pi\pi}$ and $\mathcal{S}_{\pi\pi}$ are used for the BaBar result. The case that CP symmetry is conserved, $\mathcal{A}_{\pi\pi} = \mathcal{S}_{\pi\pi} = 0$, is ruled out at the 99.93% confidence level (C.L.), equivalent to 3.4σ significance for Gaussian errors from the Belle result. More data is necessary to clarify the difference between the Belle result and the BaBar result.

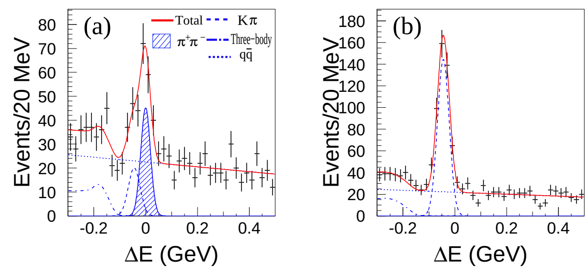

Figure 1. ΔE distributions in the M_{bc} signal region for (a) $B^0 \to \pi^+\pi^-$ candidates and (b) $B^0 \to K^+\pi^-$ candidates with $LR > 0.825$ from the Belle Collaboration. The sum of the signal and background functions is shown as a solid curve. The solid curve with hatched area represents the $\pi^+\pi^-$ component, the dashed curve represents the $K^+\pi^-$ component, the dotted curve represents the continuum background, and the dot-dashed curve represents the charmless three-body B decay background component.

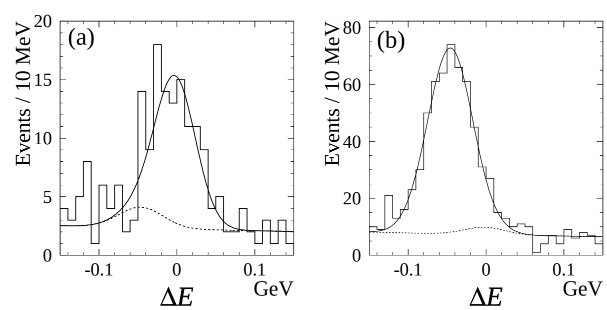

Figure 2. ΔE distributions for events enhanced in signal (a) $\pi^+\pi^-$ and (b) $K^\mp\pi^\pm$ candidates from the BaBar Collaboration. Solid curves represent projections of the maximum likelihood fit, dashed curves represent $q\bar{q}$ and $\pi\pi \leftrightarrow K\pi$ cross-feed background.

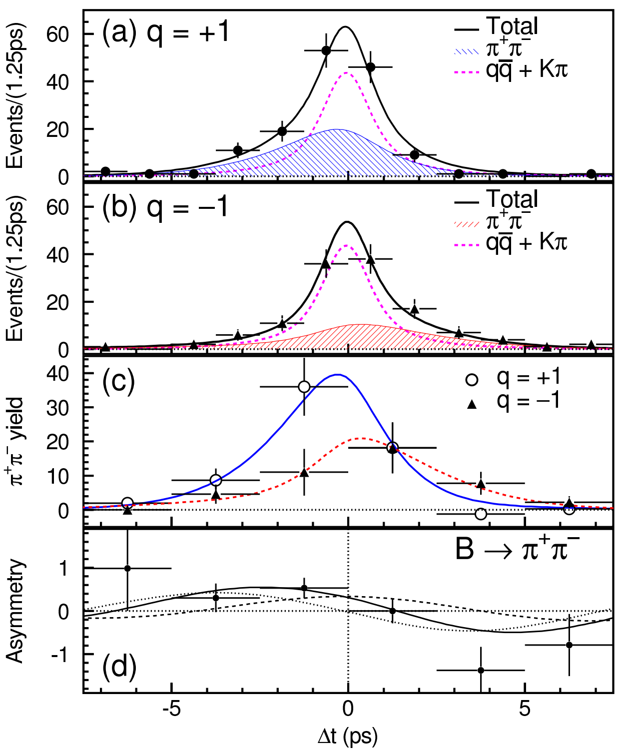

Figure 3. The raw, unweighted Δt distributions for $B^0 \to \pi^+\pi^-$ candidates with $LR > 0.825$ in the signal region from the Belle Collaboration: (a) candidates with $q = +1$, i.e. the tag side is identified as B^0; (b) candidates with $q = -1$; (c) $B^0 \to \pi^+\pi^-$ yields after background subtraction; (d) the CP asymmetry for $B^0 \to \pi^+\pi^-$ after background subtraction. In Figs. (a) through (c), the solid curves show the results of the unbinned maximum likelihood fit to the Δt distributions of the whole $B^0 \to \pi^+\pi^-$ candidates. In Fig. (d), the dashed (dotted) curve is the contribution from the cosine (sine) term.

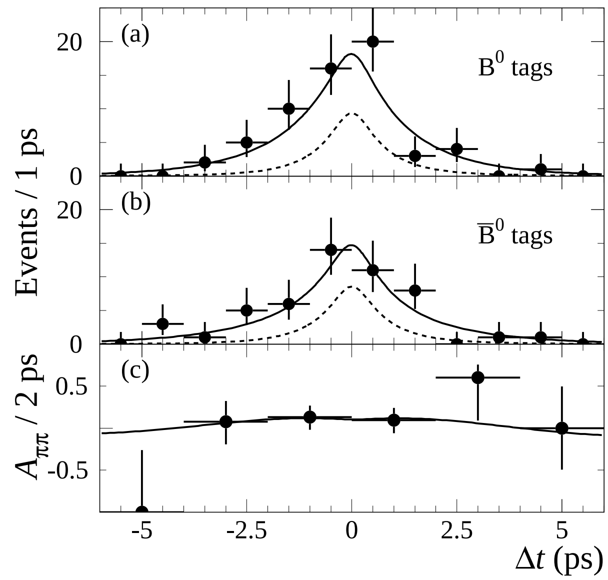

Figure 4. Distributions of Δt for events enhanced in signal $\pi\pi$ decays from the BaBar Collaboration: the tag side is identified as (a) B^0 or (b) $\bar{B}^0$, and (c) the asymmetry as a function of Δt. Solid curves represent projections of the maximum likelihood fit, dashed curves represent the sum of $q\bar{q}$ and $K\pi$ background events.

The decay amplitudes for B^0 and $\bar{B}^0$ to $\pi^+\pi^-$ can be written by using the c-convention notation [14]:

$$\begin{aligned} A(B^0 \to \pi^+\pi^-) &= -(|T|e^{i\delta_T}e^{i\phi_3} + |P|e^{i\delta_P}), \\ A(\bar{B}^0 \to \pi^+\pi^-) &= -(|T|e^{i\delta_T}e^{-i\phi_3} + |P|e^{i\delta_P}), \end{aligned} \tag{3}$$

where T and P are the amplitudes for the tree and penguin graphs and δ_T and δ_P are their strong phases. The expressions for $\mathcal{S}_{\pi\pi}$ and $\mathcal{A}_{\pi\pi}$ are

$$\begin{aligned} \mathcal{S}_{\pi\pi} &= [\sin 2\phi_2 + 2|P/T|\sin(\phi_1 - \phi_2)\cos\delta \\ &\quad - |P/T|^2 \sin 2\phi_1]/\mathcal{R}_{\pi\pi}, \\ \mathcal{A}_{\pi\pi} &= -[2|P/T|\sin(\phi_2 + \phi_1)\sin\delta]/\mathcal{R}_{\pi\pi}, \\ \mathcal{R}_{\pi\pi} &= 1 - 2|P/T|\cos\delta\cos(\phi_2 + \phi_1) + |P/T|^2, \end{aligned} \tag{4}$$

where the strong phase difference $\delta \equiv \delta_P - \delta_T$. When $\mathcal{A}_{\pi\pi}$ is positive and $0^\circ < \phi_1 + \phi_2 < 180^\circ$, δ is negative. Fig. 6 shows the two-dimensional confidence regions in the $\mathcal{A}_{\pi\pi}$ vs. $\mathcal{S}_{\pi\pi}$ plane together with the pQCD prediction [15] for various values of ϕ_2 ($= \alpha$). Fig. 7 shows predictions for $C_{\pi\pi}$ ($= -\mathcal{A}_{\pi\pi}$) and $\mathcal{S}_{\pi\pi}$ for several analysis steps with experimental and theoretical constraints [16]. In Fig. 8, the interpretation of the confidence regions of $\mathcal{A}_{\pi\pi}$ vs. $\mathcal{S}_{\pi\pi}$ is shown in terms of ϕ_2 and δ for the Belle data [10]. The range of ϕ_2 that corresponds to the 95.5% C.L. region of $\mathcal{A}_{\pi\pi}$ and $\mathcal{S}_{\pi\pi}$ is $78^\circ \le \phi_2 \le 152^\circ$ for $\phi_1 = 23.5^\circ$ [17] and $0.15 \le |P/T| \le 0.45$ [18]. The result is in agreement with

constraints on the unitarity triangle from other measurements [19]. Other interpretations for the current results can be found in ref. [16].

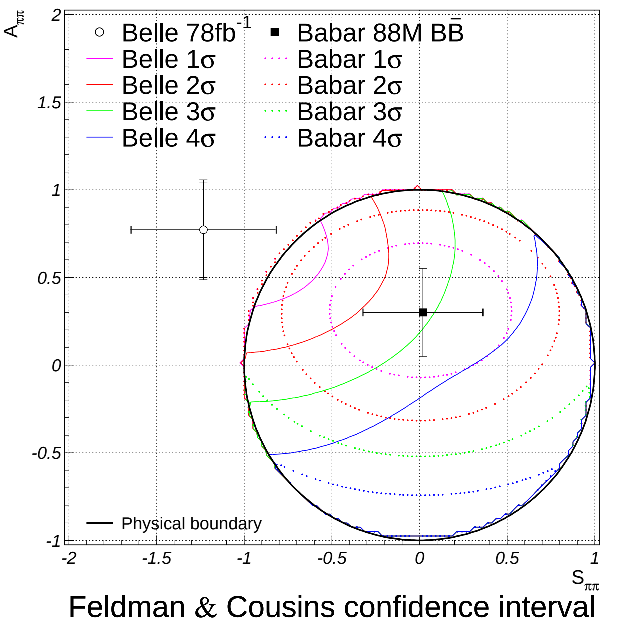

Figure 5. Confidence regions for $\mathcal{A}_{\pi\pi}$ and $\mathcal{S}_{\pi\pi}$ from the Belle and BaBar results.

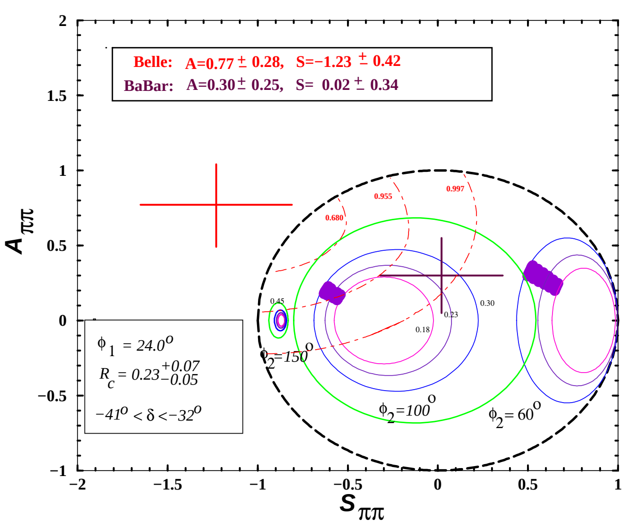

Figure 6. Plot of $\mathcal{A}_{\pi\pi}$ versus $\mathcal{S}_{\pi\pi}$ for various values of ϕ_2 with ϕ_1=24.0°, 0.18 < R_C < 0.30, and −41° < δ < −32° in the pQCD method. Here $R_C = |P/T|$. Dark areas are allowed regions in the pQCD method for different ϕ_2 values. The results of $\mathcal{A}_{\pi\pi}$ and $\mathcal{S}_{\pi\pi}$ from the Belle and BaBar Collaborations and the confidence regions from the Belle Collabolation are also shown.

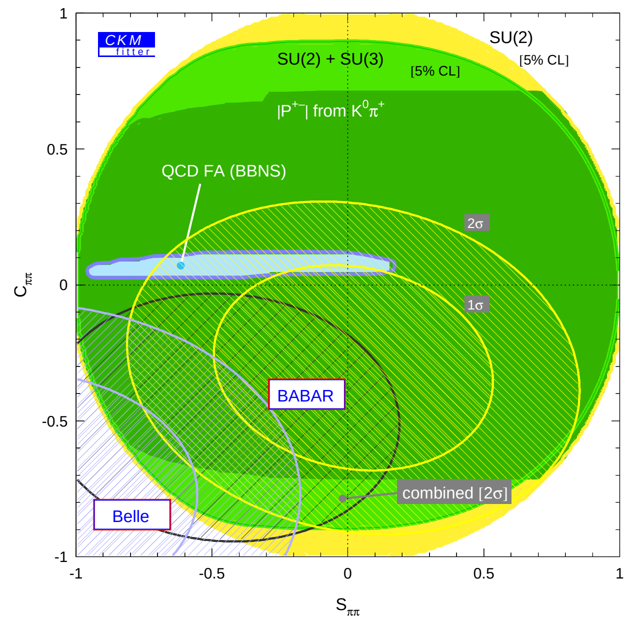

Figure 7. Predictions for $C_{\pi\pi}$ (= $-\mathcal{A}_{\pi\pi}$) and $\mathcal{S}_{\pi\pi}$ for several analysis steps with experimental and theoretical constraints. The Belle and BaBar results are shown.

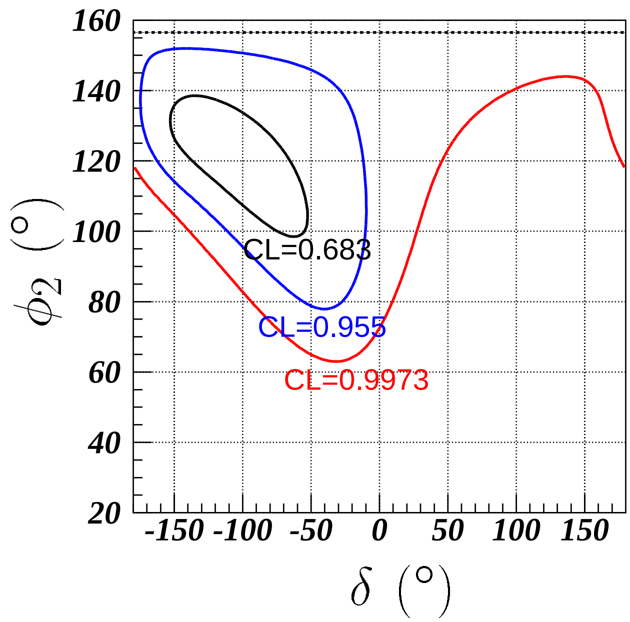

Figure 8. The region for ϕ_2 and δ which corresponds to the 68.3%, 95.5%, and 99.73% C.L. regions of $\mathcal{A}_{\pi\pi}$ and $\mathcal{S}_{\pi\pi}$ from the Belle result in Fig. 6. ϕ_1 = 23.5° and $|P/T|$ = 0.45. The horizontal dashed line corresponds to $\phi_2 = 180° - \phi_1$.

Using isospin relations [20], we can constrain the difference, θ between α_{eff} and α. From the central values of the recent world average values of the branching ratios of $B^0 \to \pi^+\pi^-$, $B^+ \to \pi^+\pi^0$ and the 90% C.L. upper limit on the $B^0 \to \pi^0\pi^0$ branching ratio [21] together with $C_{\pi\pi}$, the upper limit on θ is 54°.

3 $B^0 \to \rho\pi \to \pi^+\pi^-\pi^0$ decays

In principle, the CKM angle α can be measured in the presence of penguin contributions using a full Dalitz plot analysis of the final state. However, there are difficulties of combinatorics and lower efficiency in three-body topology with π^0 and large backgrounds from misreconstructed signal events and other decays. In order to extract α cleanly, data with large statistics are required.

Unlike $B^0 \to \pi^+\pi^-$ decay, $B^0 \to \rho^\pm\pi^\mp$ decay is not a CP eigenstate, and four flavor-charge configurations $(B^0(\overline{B}^0) \to \rho^\pm\pi^\mp)$ must be considered. Following a quasi-two-body approach [22], the analysis is restricted to the two regions of the $\pi^\pm\pi^0 h^\pm$ Dalitz plot ($h = \pi$ or K) that are dominated by $\rho^\pm h^\mp$. The decay rate is given by

$$\begin{aligned} f_q^{\rho^\pm h^\mp}(\Delta t) &= (1 \pm A_{CP}^{\rho h})\frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}} \\ &\times [1 + q\cdot((S_{\rho h} \pm \Delta S_{\rho h})\sin(\Delta m_d \Delta t) \\ &- q\cdot(C_{\rho h} \pm \Delta C_{\rho h})\cos(\Delta m_d \Delta t))], \end{aligned} \quad (5)$$

where $\Delta t = t_{\rho h} - t_{\rm tag}$ as the time interval between the decay of $B^0_{\rho h}$ and that of the other B^0 meson in the event, $B^0_{\rm tag}$.

The time- and flavor-integrated charge asymmetries $A_{CP}^{\rho\pi}$ and $A_{CP}^{\rho K}$ measure direct CP violation. For the $\rho\pi$ mode, the quantities $S_{\rho\pi}$ and $C_{\rho\pi}$ parameterize mixing-induced CP violation related to the CKM angle α, and flavor-dependent direct CP violation, respectively. $\Delta C_{\rho\pi}$ describes the asymmetry between the rates $\Gamma(B^0 \to \rho^+\pi^-) + \Gamma(\overline{B}^0 \to \rho^-\pi^+)$ and $\Gamma(B^0 \to \rho^-\pi^+) + \Gamma(\overline{B}^0 \to \rho^+\pi^-)$. $\Delta S_{\rho\pi}$ is related to the strong phase difference between the amplitudes contributing to $B^0 \to \rho\pi$ decays. One finds the relations $S_{\rho\pi} \pm \Delta S_{\rho\pi} = \sqrt{1 - (C_{\rho\pi} \pm \Delta C_{\rho\pi})^2}\sin(2\alpha^\pm_{\rm eff} \pm \delta)$, where $2\alpha^\pm_{\rm eff} = \arg[(q/p)(\overline{A}^\pm_{\rho\pi}/A^\mp_{\rho\pi})]$, $\delta = \arg[A^-_{\rho\pi}/\overline{A}^+_{\rho\pi}]$, arg[q/p] is the B^0-$\overline{B}^0$ mixing phase, and $A^+_{\rho\pi}(\overline{A}^+_{\rho\pi})$ and $A^-_{\rho\pi}(\overline{A}^-_{\rho\pi})$ are the transition amplitudes of the processes $B^0(\overline{B}^0) \to \rho^+\pi^-$ and $B^0(\overline{B}^0) \to \rho^-\pi^+$, respectively. The angles $\alpha^\pm_{\rm eff}$ are equal to α if contributions from penguin amplitudes are absent. For the self-tagging ρK mode, the values of the four time-dependent parameters are $C_{\rho K} = 0$, $\Delta C_{\rho K} = -1$, $S_{\rho K} = 0$, and $\Delta S_{\rho K} = 0$. The results on direct CP violation can be expressed using the asymmetries

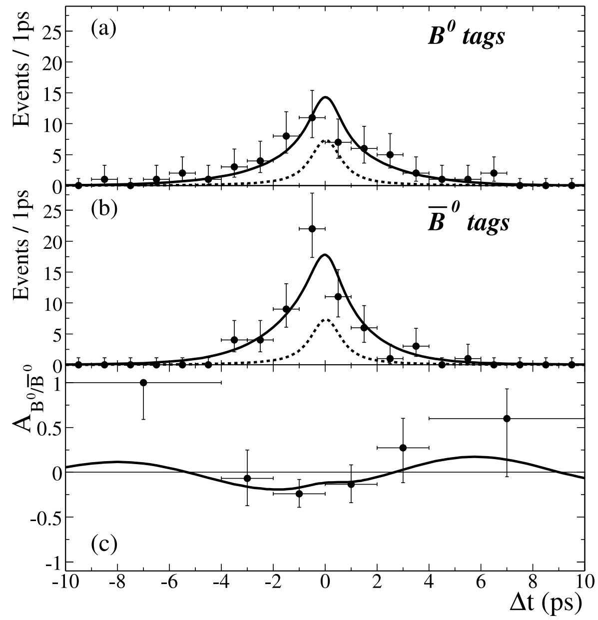

Figure 9. Time distributions for events selected to enhance the $\rho\pi$ signal tagged as (a) B^0-tag and (b) $\overline{B}^0$-tag, and (c) time-dependent asymmetry between B^0-tag and $\overline{B}^0$-tag from the BaBar Collaboration [23]. The solid curve is a likelihood projection of the fit result. The dashed line is the sum of B- and continuum-background contributions.

$$\begin{aligned} A_{+-} &= \frac{N(\overline{B}^0_{\rho\pi} \to \rho^+\pi^-) - N(B^0_{\rho\pi} \to \rho^-\pi^+)}{N(\overline{B}^0_{\rho\pi} \to \rho^+\pi^-) + N(B^0_{\rho\pi} \to \rho^-\pi^+)} \\ &= \frac{A_{CP}^{\rho\pi} - C_{\rho\pi} - A_{CP}^{\rho\pi}\cdot\Delta C_{\rho\pi}}{1 - \Delta C_{\rho\pi} - A_{CP}^{\rho\pi}\cdot C_{\rho\pi}} \end{aligned} \quad (6)$$

$$\begin{aligned} A_{-+} &= \frac{N(\overline{B}^0_{\rho\pi} \to \rho^-\pi^+) - N(B^0_{\rho\pi} \to \rho^+\pi^-)}{N(\overline{B}^0_{\rho\pi} \to \rho^-\pi^+) + N(B^0_{\rho\pi} \to \rho^+\pi^-)} \\ &= \frac{A_{CP}^{\rho\pi} + C_{\rho\pi} + A_{CP}^{\rho\pi}\cdot\Delta C_{\rho\pi}}{1 + \Delta C_{\rho\pi} + A_{CP}^{\rho\pi}\cdot C_{\rho\pi}} \end{aligned} \quad (7)$$

With a data sample of 89 million $B\overline{B}$ pairs [23], the BaBar Collaboration found 428^{+34}_{-33}(stat) $\rho\pi$ and 120^{+21}_{-20}(stat) ρK events and the following measurements of the CP violation parameters are obtained:

$$\begin{aligned} A_{CP}^{\rho\pi} &= -0.18 \pm 0.08 \pm 0.03, \\ C_{\rho\pi} &= +0.36 \pm 0.18 \pm 0.04, \\ S_{\rho\pi} &= +0.19 \pm 0.24 \pm 0.03. \end{aligned}$$

For the other parameters in the description of the $B^0(\overline{B}^0) \to \rho\pi$ decay-time dependence,

$$\begin{aligned} \Delta C_{\rho\pi} &= +0.28 \pm 0.19 \pm 0.04, \\ \Delta S_{\rho\pi} &= +0.15 \pm 0.25 \pm 0.03, \end{aligned}$$

are found. For the asymmetries A_{+-} and A_{-+}, which probe direct CP violation,

$$A_{+-} = -0.62^{+0.24}_{-0.28} \pm 0.06,$$
$$A_{-+} = -0.11^{+0.16}_{-0.17} \pm 0.04,$$

are measured. The raw time-dependent asymmetry in the tagging categories dominated by kaons and leptons is shown in Fig. 9.

4 Prospects

Table 1 shows the expected error on CP-violating parameters in $B^0 \to \pi^+\pi^-$ and $B^0 \to \rho^\pm\pi^\mp$ decays with accumulated luminosities of 140 fb^{-1}, 400 fb^{-1}, 3000 fb^{-1} (3 ab^{-1}), and 30000 fb^{-1} (30 ab^{-1}) in the future.

Fig. 10 shows the prospects of $\alpha_{eff} - \alpha$ for the ICHEP'02 central values of the $B \to \pi\pi$ branching ratios and the central values of $\mathcal{S}_{\pi\pi}$ and $\mathcal{C}_{\pi\pi}$ from the BaBar measurement at luminosities of the current and future B-factories (87 fb^{-1}, 500 fb^{-1}, 2 ab^{-1}, 10 ab^{-1}). The inner and outer boarders can be obtained from the isospin analysis when $B^0 \to \pi^0\pi^0$ flavors are tagged and not tagged, respectively. Only a luminosity of around 10 ab^{-1} allows to separate the solutions.

For $B \to \rho\pi$ decays, the isospin analysis is not feasible yet with the present statistics of the B factories. In [24], the projections into the future full SU(2) analysis was demonstrated. If the branching fraction of $B^0 \to \rho^0\pi^0$ is below the experimental sensitivity, a strong constraint on α is expected above luminosity of around 2 ab^{-1}. In this workshop, theoretical problems such as form factors and σ meson [25], and experimental problems for several sources of backgrounds were pointed out.

Detailed discussions can be found in [27] for $B^0 \to \pi^+\pi^-$ and in [24] for $B^0 \to \rho\pi$ at this workshop.

parameters	140 fb^{-1}	400 fb^{-1}	3 ab^{-1}	30 ab^{-1}
$\mathcal{A}_{\pi\pi}$	0.21	0.13	0.05	0.02
$\mathcal{S}_{\pi\pi}$	0.31	0.19	0.07	0.03
$A_{CP}^{\rho\pi}$	0.07	0.04	0.02	0.008
$C_{\rho\pi}$	0.14	0.09	0.03	0.013
$S_{\rho\pi}$	0.18	0.11	0.04	0.014

Table 1. The errors of CP-violating parameters in $B^0 \to \pi^+\pi^-$ and $B^0 \to \rho^\pm\pi^\mp$ decays at 140 fb^{-1}, 400 fb^{-1}, 3 ab^{-1}, and 30 ab^{-1}, assuming that statistical and systematic errors are proportional to $1/\sqrt{\mathcal{L}}$ and $1/\sqrt[4]{\mathcal{L}}$, respectively. Here L is accumulated luminosity.

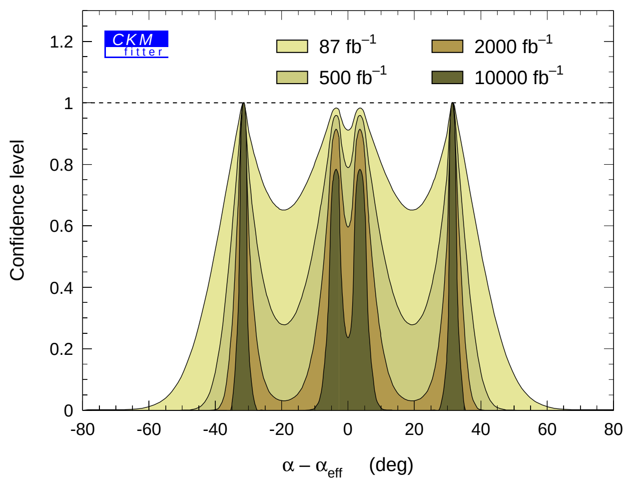

Figure 10. $\alpha_{eff} - \alpha$ for the ICHEP'02 central values of the $B \to \pi\pi$ branching fractions and the central values of $\mathcal{S}_{\pi\pi}$ and $\mathcal{C}_{\pi\pi}$ from the BaBar measurement at luminosities of the current and future B-factories (87 fb^{-1}, 500 fb^{-1}, 2 ab^{-1}, and 10 ab^{-1}).

5 Summary

In summary, the Belle and BaBar Collaborations obtain the following measurements of the CP-violating asymmetry parameters in $B^0 \to \pi^+\pi^-$ decays:

$$\mathcal{A}_{\pi\pi} = +0.77 \pm 0.27 \pm 0.08, \quad \mathcal{S}_{\pi\pi} = -1.23 \pm 0.41^{+0.08}_{-0.07} \quad \text{(Belle)},$$
$$\mathcal{A}_{\pi\pi} = +0.30 \pm 0.25 \pm 0.04, \quad \mathcal{S}_{\pi\pi} = -0.02 \pm 0.34 \pm 0.05 \quad \text{(BaBar)},$$

The following measurements of the CP-violating asymmetry parameters in $B^0 \to \rho\pi$ decays using a quasi two-body analysis are obtained by the BaBar Collaboration:

$$A_{CP}^{\rho\pi} = -0.18 \pm 0.08 \pm 0.03,$$
$$C_{\rho\pi} = +0.36 \pm 0.18 \pm 0.04, \quad \Delta C_{\rho\pi} = +0.28 \pm 0.19 \pm 0.04,$$
$$S_{\rho\pi} = +0.19 \pm 0.24 \pm 0.03, \quad \Delta S_{\rho\pi} = +0.15 \pm 0.25 \pm 0.03.$$

For the asymmetries A_{+-} and A_{-+}, which probe direct CP violation,

$$A_{+-} = -0.62^{+0.24}_{-0.28} \pm 0.06, \qquad A_{-+} = -0.11^{0.16}_{-0.17} \pm 0.04,$$

are obtained.

References

1. M. Kobayashi and T. Maskawa, Prog. Theor. Phys. **49**, 652 (1973).

2. ϕ_1 $(= \beta) \equiv \arg[-V_{cd}V^*_{cb}/V_{td}V^*_{tb}]$, ϕ_2 $(= \alpha) \equiv \arg[-V_{td}V^*_{tb}/V_{ud}V^*_{ub}]$, and ϕ_3 $(= \gamma) \equiv \arg[-V_{ud}V^*_{ub}/V_{cd}V^*_{cb}]$.
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4. BaBar Collaboration, B Aubert *et al.*, Phys. Rev. Lett. **89**, 201802 (2002).
5. Throughout this paper, the inclusion of the charge conjugate mode decay is implied unless otherwise stated.
6. $C_{\pi\pi} = -\mathcal{A}_{\pi\pi}$. The BaBar Collaboration uses $C_{\pi\pi}$ and the Belle Collaboration uses $\mathcal{A}_{\pi\pi}$. Usually the partial-rate asymmetry or direct *CP* violation parameter is defined by $[N(\overline{B} \to \overline{f}) - N(B \to f)]/[N(\overline{B} \to \overline{f}) + N(B \to f)]$. Its sign is consistent with the sign of $\mathcal{A}_{\pi\pi}$. Here B represents either a B^0 or B^+ meson, f represents a flavor-specific final state, and $\overline{B}^0$ and $\overline{f}$ are their conjugates.
7. The Belle Collaboration uses the beam-energy constrained mass $M_{\rm bc}$. The BaBar Collaboration uses the beam-energy substituted mass $m_{\rm ES} = \sqrt{(s/2 + \mathbf{p_i}\cdot\mathbf{p_B})^2/E_i^2 - \mathbf{p_B^2}}$, where $\sqrt{s}$ is the total cms energy , and the B momentum $\mathbf{p_B}$ and the four-momentum of the initial state $(E_i, \mathbf{p}_i)$ are defined in the laboratory frame.
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